THE OUTLINE OF NEW ZEALAND

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A thorough appreciation of scenery involves not merely the perception of its beauty but also some understanding of its meaning in connection with the history of the earth. This meaning is not always perfectly obvious, but the real seeker is not dismayed by the difficulty of the quest. The shores of New Zealand are a veritable treasure house of beauty, rivaling in their charm the glaciers of the southern island, the geysers of the northern, and the mountains, lakes, and gorges of both. What story is it that these fascinating coasts reveal?

Peculiarities of the Coast Line

An examination of a map of the islands of New Zealand (Fig. 1) shows us a number of peculiarities in the outlines which demand explanation. The sprawling North Island and the more compact but narrow-waisted South Island suggest a decipherable coast history. Numerous embayments characterize certain areas as the loci of submergence; but, to the reader of an outline map, the intervening stretches of coast are generally enigmatical. Such portions, however, yield more information to the student in the field.

In a previously published article[1] the writer called attention to the occurrence of multicycle fault coasts, or, in other words, coasts initiated by faulting and subsequently uplifted intermittently during their modification by wave action and subaërial agencies.[2] It is proposed now to make a rapid survey in order to classify the coastal types represented.

The Broad Outlines

Geologic History

An investigation of the broad outlines of the New Zealand land masses necessitates an excursion into the realm of historical geology, and it becomes necessary to define what is to be understood by the name "New Zealand." To some it would mean not only the existing land but also any land that has ever been emergent on the site of the present New Zealand area; and this would be a perfectly justifiable view if it appeared that

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[1] C. A. Cotton: Fault Coasts in New Zealand, *Geogr. Rev.*, Vol. 1, 1916, pp. 20-47.

[2] In the article referred to (p. 21) a somewhat misleading statement was made that fault coasts had not been recognized by geomorphologists of the American school. The statement was intended to refer to the non-recognition of the type in systematic classifications of coast forms in textbooks and similar works; but, as it stands, it does injustice to some workers, notably Vaughan and Lawson, who have indicated an origin by faulting for the coasts of Cuba and California respectively.

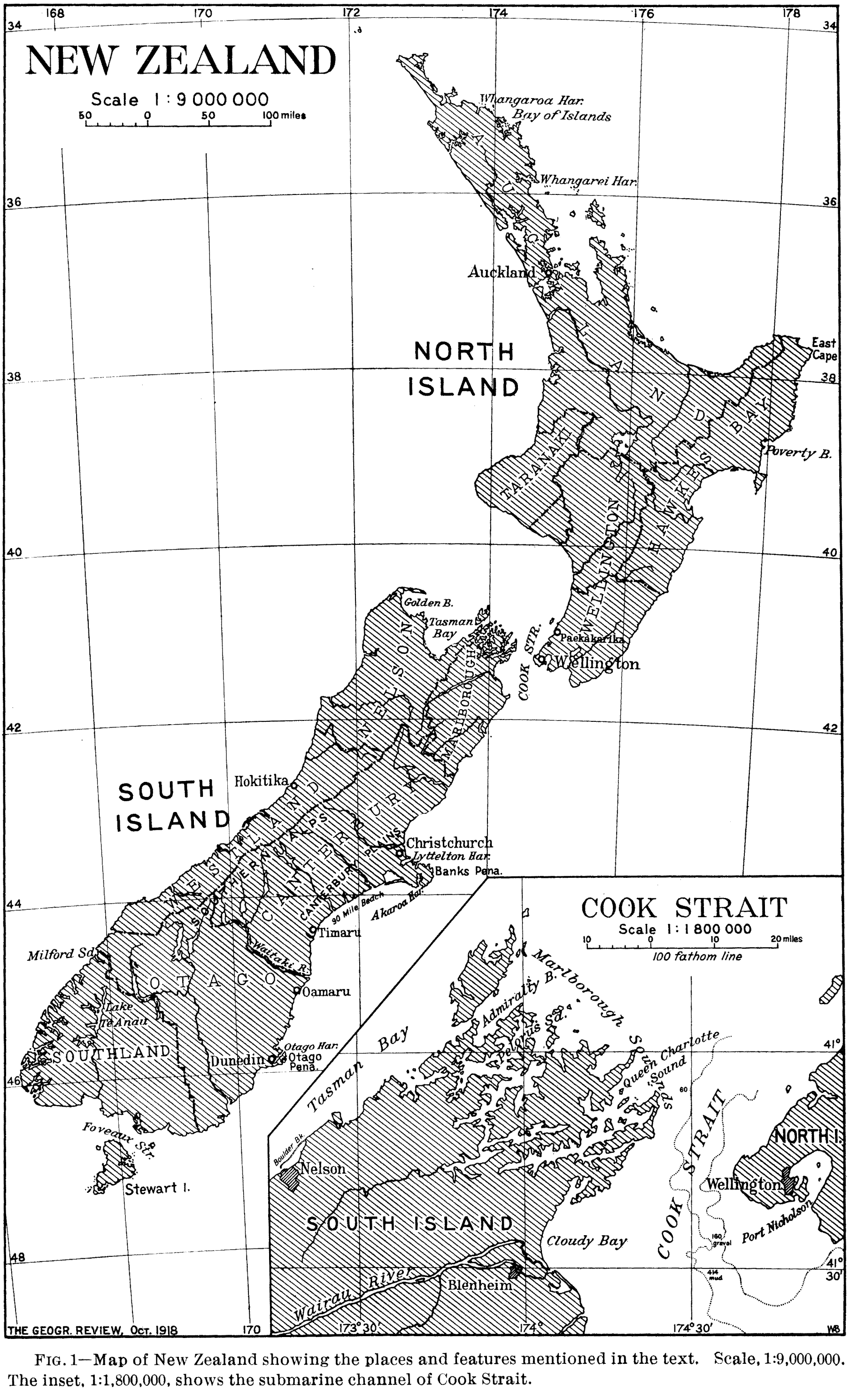

FIG. 1—Map of New Zealand showing the places and features mentioned in the text. Scale, 1:9,000,000. The inset, 1:1,800,000, shows the submarine channel of Cook Strait.

the axis of such land had always coincided more or less exactly with the axis of the present-day New Zealand—if, in other words, there were a recognizable nucleus about which the land had been built during a succession of submergences. But such is not the case.

In late Paleozoic and early Mesozoic times the site of New Zealand was the locus of accumulation of vast masses of coarse-grained sediments. An orogenic period followed, but nothing is known as to the extent of the resulting land except that it was of large dimensions. Its outlines are quite unknown, and it seems inadvisable to think of it as an ancestral New Zealand. Next followed a period of planation succeeded by Cretaceous and Tertiary sedimentation,[3] and it was only at the end of this that there arose, as a concourse of earth blocks, the initial forms of the present New Zealand land mass.[4] This, then, is New Zealand for the geologist, but its outlines were undoubtedly very different initially from those of the group of islands constituting the New Zealand of geography.

Present-Day New Zealand

To some small extent the present outlines may be survivals of the boundaries of the nascent land modified by later regional uplift and depression as well as by weather and waves. On the other hand some parts at least of the coasts are the sequential forms—generally multicycle sequential forms—developed from lines of fracture bounding a residual mass after marginal portions had foundered.[5] This foundering took place in relatively modern times, perhaps contemporaneously with some vertical movements by which the land has been divided into large differentially moving areas.[6] Prior to these coast-determining subsidences, though the area of the land was greater, its general outlines, especially in the south, may be assumed to have been roughly similar to those of modern New Zealand; for the axis about which the constituent earth blocks are heaped coincides in a general way with the trend of the existing land, and the low-lying blocks, generally speaking, are marginal.

Weak strata, deposited in the period immediately preceding the birth of the New Zealand land mass, survive over considerable areas on these marginal blocks because of the lowly position which they occupied with respect to base level during a long interval of less emergence than that of the present day. Their marginal occurrence led to a belief among early geological observers, who failed to note the evidence of more recent deformation, that these Tertiary strata were laid down around the coasts

[3] C. A. Cotton: The Structure and Later Geological History of New Zealand. *Geol. Mag.*, Decade 6, Vol. 3, 1916, pp. 243-249 and 314-320; reference on pp. 246-248. Reviewed in the *Geogr. Rev.*, Vol. 3, 1917, pp. 83-84.

[4] *Ibid.*, pp. 248 and 319-320.

[5] F. von Hochstetter: Geologie von Neuseeland, in "Reise der österreichischen Fregatte Novara um die Erde," Geol. Teil., I, Vienna, 1864, p. xlvi; E. Suess: The Face of the Earth (Engl. transl.), Vol. 2, Oxford, 1906, p. 144; C. A. Cotton, paper cited in footnote 1.

[6] C. A. Cotton, paper cited in footnote 3; reference on pp. 318-319.

and in the drowned valleys of a land surface carved by erosion from a folded range uplifted in the late Jurassic. The amount of submergence postulated to allow of the deposition of these younger strata was never sufficient, however, to allow of breaks in the continuity of the erosion of the axial mountain mass. Geologists of the latter half of the nineteenth century were not repelled by the idea of still-surviving, one-cycle Mesozoic mountains.[7]

The more modern explanation of the relief, which has been outlined on an earlier page, assigns the differential uplift of the more mountainous areas, as well as the emergence of marginal and intermont districts upon which are still preserved portions of the formerly widespread cover, to a period of uplift and deformation of very much later date—later, that is to say, than the period of deposition of the Tertiary sediments.

Recent Movements

All parts of New Zealand have been affected by recent vertical movements, and a fault coast depressed sufficiently, either as an accompaniment of or at any stage later than the initial faulting, loses most of its individuality as a fault coast and becomes scarcely if at all recognizable as such. It is thus difficult to determine whether all or only some of the outlines of New Zealand resulted from marginal foundering. No definite information on this point has been gained from a study of the continental shelf; but, if a number of variables can be given their proper value, a study of the width of the shelf ought to tell something of the time that has elapsed since the initiation of the coast of which it forms a part. Nothing, however, can be more striking than the rapidity, judged by the rate of contemporaneous subaërial erosion, with which a normal, graded shelf is developed in connection with a young coast.[8]

Cook Strait

New Zealand consists of two main islands and a few smaller ones. To a New Zealander the two large islands are the mainland of his country. So closely are they related that they have not really separate names. On a map they appear as "North Island" and "South Island," but they are spoken of as "the North Island (of New Zealand)" and "the South Island

[7] The following passage from Hutton is quoted with approval by Suess: "Mountains with sharply jagged peaks are the exception in Switzerland, and the rule in New Zealand. Waterfalls are rare in New Zealand; a few occur up the deep fjords of the south-west coast, and some few small ones at the heads of the valleys in the great ranges. Yet the Alps of New Zealand are quite as bold and steep as those of Switzerland; their ravines are even more numerous and deeper. The passes are deeper in New Zealand, the valleys much more terraced, and the mountains on the whole more extensively covered by loose débris than in Switzerland. This is certainly truer of Canterbury, Nelson, and Marlborough than of Otago. The explanation lies in the fact that the Alps of New Zealand are *by far the older*. They have been exposed to the action of the weather, at least in part, since the Jurassic period, and many of the larger valleys were already excavated, almost to their existing depth, before the Oligocene period." (E. Suess *op. cit.*, p. 148.)

[8] C. A. Cotton, paper cited in footnote 1; reference on p. 37.

(of New Zealand)." It is as though one spoke of "the northern part" and "the southern part" of a country.

Origin of Cook Strait

The close political association of the two islands is a result, no doubt, of their isolation from the rest of the world: it has come about in spite of striking physical differences between them—differences which lead to an inquiry as to the origin of the dividing strait. The origin of this channel, Cook Strait, has been ascribed to (1) subsidence, with drowning of the valley of a great river; (2) dislocation; and (3) subsidence of earth blocks.

The River Theory

The first of these, the Cook Strait River theory, was advocated by Crawford.[9] Hutton[10] also ascribed the separation of the islands to regional subsidence. The theory is inadequate, as it involves a great subsidence of all the land bordering the strait, while it is only locally that there is any evidence of subsidence, the most general movements having been of uplift.

The Fault Theory

The dislocation, or Cook Strait Fault, theory was put forward by Hochstetter[11] but afterwards abandoned. It was revived by Park.[12] According to Hochstetter—

> In the early geological era of New Zealand we may assume that both islands were connected and that one backbone ran continuously from the South Cape to the East Cape. In the present map of New Zealand the integrity of this backbone is broken at Cook's Straits, and a closer inspection will show that there has been not only a simple break of continuity, but a lateral dislocation . . . . . . It is evident, from the rocks being of the same geological formation, that at one period the Pelorus ranges were a continuation of the Wellington ranges. The position of the strata in the eastern ranges of Nelson proves that, whilst the Northern island seems to have remained stationary, some gigantic force has pressed the great mass of the Middle [South] Island to the westward.

Park states that the "North Island has been thrust eastward some distance relatively to the South Island." Of this relative movement of some fifty miles there is no satisfactory field evidence, and the theory has nothing to recommend it.

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[9] J. C. Crawford: Did the Great Cook Strait River Flow to the Northwest or to the Southwest? *Trans. and Proc. New Zealand Inst.*, Vol. 7, 1875, pp. 448-451.

Idem: Some Further Proofs as to the Ancient Cook Strait River . . . . also a Consideration of the Date at which the Islands were United, *ibid.*, pp. 451-453.

[10] F. W. Hutton: The Geological History of New Zealand, *Trans. and Proc. New Zealand Inst.*, Vol. 32 1899, pp. 159-183; reference on p. 178.

[11] F. von Hochstetter: Lecture on the Geology of the Province of Nelson, in "The Geology of New Zealand," by Hochstetter and Petermann, Auckland, 1864, pp. 77-108; reference on p. 106 (first published in *New Zealand Government Gazette*, 1859).

[12] J. Park: Geology of New Zealand, Christchurch, 1910, p. 262.

The Subsidence Theory

Hochstetter's later theory to account for Cook Strait as the result of subsidence of earth blocks was stated as follows:

> Indem aber das Land durch Hebung, durch Anschwemmung und durch das Hervorbrechen der Vulcane einen nicht unbedeutenden Zuwachs erhielt, versanken andere Theile gleichzeitig in die Tiefe. Einem solchen Ereignisse mag die Bildung der Cooks- und Foveaux-Strasse ihren Ursprung verdanken.[13]

Hochstetter no longer felt the necessity of assuming lateral dislocation, for, as Suess points out, he was now "aware that the mountain chain which follows the east coast of North Island from East Cape to Wellington is continued on the other side of Cook Strait between the east coast of South Island and the river Awatere."[14]

When the evidence is recalled of great differential movement between adjacent blocks on both sides of the strait, both in the mountain-building period and in the later period of vertical movements, it seems highly probable that this explanation of the formation of Cook Strait is the correct one. Possibly the statement ought to be modified by substituting for the phrase "subsidence of earth blocks" another reading "failure of blocks to rise along with the adjacent blocks which now constitute the northern part of the South and the southern part of the North Island." There is, however, a biological argument in the identity, or at any rate close affinity, of northern and southern species of moas for the belief that the dry land areas of the two islands were at one time connected,[15] though, according to Hutton, the differences in these flightless birds are such as to lead him to believe the period of separation to be rather ancient. This justifies the adoption of a tentative hypothesis that at the close of the orogenic movements which gave birth to the New Zealand land mass the dividing strait was not in existence and that the separation of the two islands has taken place subsequently as a result of a subsidence of blocks possibly contemporaneous with the partial subsidence of an adjacent portion of the South Island.

Evidence in Support of This Hypothesis

Important evidence of subsidence in the southern entrance to the strait is afforded by a channel of deep water extending into the narrows of the strait, where it is kept open by the strong scour of tidal currents. In this trench the British Admiralty chart[16] records a depth of 414 fathoms, with a mud bottom, but in 160 fathoms the presence of gravel is noted (Fig. 1, inset). In the northwestern open part of the strait, on the other hand, the maximum depth is only about 60 fathoms, for tidal currents are there too feeble to prevent the deposition of sediment in deep water. There is, therefore, a level mud bottom altogether masking the initial form of the floor.

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[13] F. von Hochstetter, work cited in footnote 5, p. xlvi.

[14] E. Suess, *op. cit.*, p. 144.

[15] F. W. Hutton, *op. cit.*, p. 177.

[16] No. 2054 (New Zealand, Sheet 5)

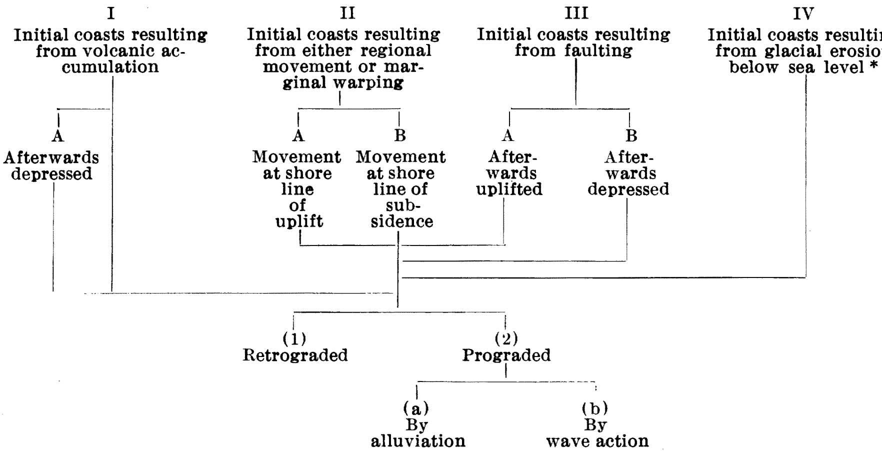
It may be noted in this connection that central New Zealand is a seismic region and that the majority of recorded shocks have been shown to proceed from points beneath the northwestern entrance of Cook Strait.[17] This perhaps indicates that subsidence along faults is still in progress.

The Existing Coasts of New Zealand

The outlines of the two main islands have thus been roughed out largely by fracture, with foundering of land to seaward; but the actual coasts, whether originating entirely in this way or preserving some parts of the outline of the initial land, are sequential forms modified as a result of emergence and submergence, retrogradation and progradation.

The following tabular classification of coasts has been found useful by the writer in making a preliminary diagnosis of the coastal types represented.

TABULAR CLASSIFICATION OF COASTS



* G. K. Gilbert: Glaciers and Glaciation (Vol. 3 of Harriman Alaska Expedition), New York, 1904; reference on pp. 210-218.

NEW ZEALAND COAST TYPES

Almost every conceivable type of coast has its representative somewhere in New Zealand's long coast line; but the principal types are as follows:

(1) Drowned coasts, the presubmergence form being generally indecipherable, but, from analogy, probably of the fault-coast type, II B, III B (1, 2).

(2) Drowned volcanic coasts, I A (1, 2).

(3) Fault coasts, all or nearly all subsequently uplifted and, therefore, multicycle fault coasts, III, III A (1, 2).

(4) Prograded coasts, 2 (a, b).

[17] See Map of Earthquake Origins, by G. Hogben, in Patrick Marshall: The Geography of New Zealand, Christchurch, 1905(?), Fig. 10, p. 219.

The Coasts of the North Island

Northern Part

The northern half of the North Island has been affected by broad regional subsidence. The evidence of land forms, however, shows that this

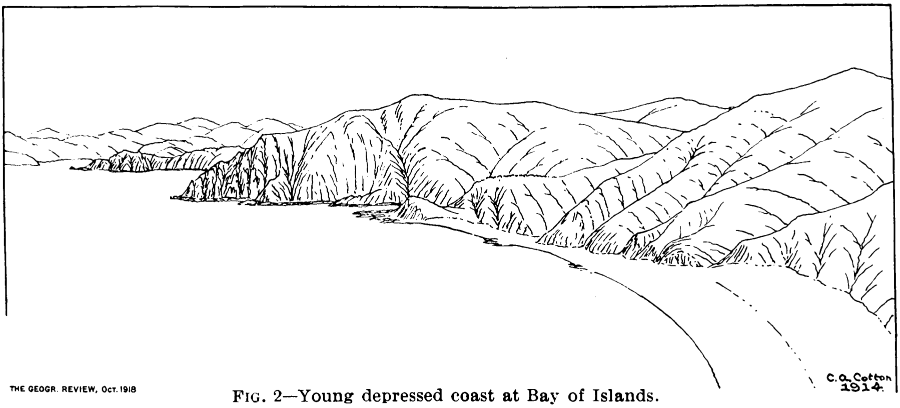


Fig. 2—Young depressed coast at Bay of Islands.

subsidence is not of great amount and that it followed still greater uplift. It would appear from the depth of water not far from the coasts that this subsidence affected a land mass roughed out previously to a shape very

Fig. 3—At Bay of Islands, northern New Zealand.

similar to that of the present land. A long period of erosion followed the roughing out of the initial coast, and so the subsidence has given a typically drowned shore line, which is now, especially on the eastern coast, still in a young stage of development (Figs. 2-6).

On the western coast, upon which great seas are continually breaking, a long, straight shore line has been developed, in part by the cutting back of headlands but principally by progradation, enormous quantities of sand having been thrown up as beaches, spits, and bars and piled as dunes upon

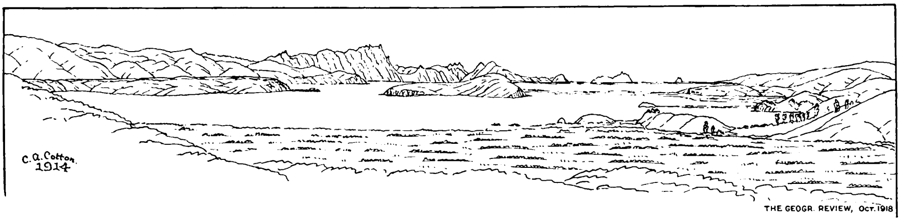


FIG. 4—Whangarei Harbor, northern New Zealand.

the foreland. This even coast is broken here and there by inlets which are the openings of drowned valley systems extending far inland. Progradation and dune formation along this coast have not been confined to the

FIG. 5—Whangaroa Harbor, northern New Zealand. (Photo from New Zealand Dept. of Tourist and Health Resorts.)

present cycle of coastal evolution, for there is a strip of soft sandstone of eolian origin with pronounced cross-bedding which must have accumulated on an advancing shore line in the period anterior to the recent submergence of the valleys that cross it and anterior also to the earlier uplift

that led to the excavation of those valleys and the mature dissection of the eolian sandstone.

This type of coast extends southward along the west coast almost to the great salient of Taranaki; while on the east coast the drowned coast reaches to Poverty Bay.

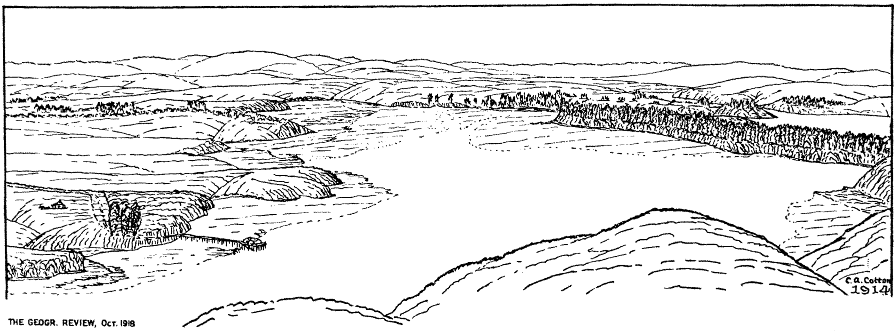


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FIG. 6—The upper reaches of Auckland Harbor.

SOUTHERN PART

In the southern part of the North Island shore lines resulting from recent subsidence are not found except locally at Wellington; and, as in the north, the land forms afford evidence of a series of movements of uplift.[18] It is not clear whether the whole of this intermittent uplift is to be correlated with the uplifts which preceded the valley-drowning subsidence in the north. Possibly the later stages of the uplift in the south took place contemporaneously with the northern subsidence, in which case the latest and most important movement in connection with the origin of the existing coasts might be regarded as a tilting of the whole island on a hinge line about midway between the extremities. This has not, however, been established, and the effects have probably been produced by movements of a less simple character.

The eastern and southern coasts may be classed as multicycle fault coasts (Figs. 7 and 8), but the latter is interrupted by a locally downwarped and embayed area occupied by Port Nicholson, the harbor of Wellington (Fig. 11).[19] That of western Wellington appears to be a mature fault coast also, but differs from the others in being prograded except at the southern end (Fig. 9). A number of features in connection with the coastal lowland bordering this coast point to alternation on a large scale between progradation and retrogradation in the period that has elapsed since the last significant movement of uplift.

The first decipherable stage in the history of the development of this western coast is a phase of retrogradation during which a mature line of

[18] C. A. Cotton: Notes on Wellington Physiography, *Trans. and Proc. New Zealand Inst.*, Vol. 44, 1911 pp. 245-265.

[19] C. A. Cotton, papers cited in footnotes 1 and 18.

cliffs was developed on the old rocks forming the core of the land. Except at the southern end of the coast, however, a foreland compounded of several elements (Fig. 10) and varying in width up to about twelve miles, now lies in front of the ancient cliffs. The material composing the foreland is of two kinds, gravel of local origin and sand which has been transported alongshore from the north. The abundance of the latter at certain times seems to have been the cause of progradation, and reversals of the process seem to have resulted from fluctuation in the supply. The sand thrown up by the sea in the first progradational phase formed, apparently,

FIG. 7—Cliffs of the southern coast of Wellington. Note the talus that has accumulated along the base of the cliffs since the small uplift of 1855.

a dune-covered foreland, while the gravel supplied by local streams would accumulate on the foreland as fans. When the foreland grew wide, the irregular surface seems to have been planed or reduced to an even seaward slope by subaërial erosion, the sand, no doubt, first becoming fixed by vegetation, as is the case on modern dunes along this coast. Then came a phase of retrogradation. At its narrow southern end the foreland was at this time cut away practically altogether, and farther north the seaward margin of the planed dunes was cut back to such an extent that revived streams dissected the sloping surface. A second extensive progradation has built a new dune-covered foreland several miles in width, between which and the margin of the older foreland (and especially in the valleys of the latter) there are some lakes and swamps, while in places the newer dunes, now fixed by vegetation, interfinger with the spurs of the older foreland. The existing gravel fans have been built in the later main progradational phase.

At the narrow southern end of the foreland, where the intermediate phase of strong retrogradation has only recently been terminated by the southward growth of the newer foreland along the coast, there are strongly marked features illustrating the four main phases in the oscillation of the shore line. The cliffs of the first retrogradational phase are now somewhat subdued and rounded by soil creep, and pass by a smooth concave curve at the base into the talus slopes and fans of the next phase—the first progradation (Fig. 13, fans on left). These fans are irregularly truncated by the cliffs developed in the second retrogradational phase, which, in

FIG. 8—An uplifted platform of the multicycle fault coast of southern Wellington.

places, are cut back far enough to intersect the line of the older cliffs (Fig. 13, center). In front of the newer line of cliffs lies the modern foreland, consisting of a belt of dunes, which are fixed on the landward side by vegetation and which enclose between them and the cliffs a narrow strip of marshy plain.

The Coasts of the South Island

NORTHERN COAST

Golden Bay and Tasman Bay, which are deep re-entrants in the northern coast, appear to be areas of subsidence connected with the Cook Strait depression. Along their shores there is evidence of uplift and also of some subsidence, the latter movement being the more recent. Thus the coast is more or less drowned, and still young, though straightened to some extent by the growth of sand and gravel spits and to a smaller extent by cliffing.

FIG. 9—The shore of Cook Strait, southwestern coast of Wellington.

FIG. 10—Extreme southern end of the foreland of western Wellington, backed by the cliffs of Paekakariki.

At the head of Tasman Bay confluent deltas of several rivers form extensive plains, while, near the head of the bay on its eastern side, an interesting feature is Nelson Haven, a sheltered harbor enclosed by a spit of coarse gravel and boulders up to the size of a man's head and even larger. This spit extends for eight miles along the shore southwestward from a high, cliffed bluff from which the rock material is derived and encloses a strip of water one to two miles in width (Fig. 12). The natural entrance to the harbor around the hooked southern end of the spit is shallow and rocky, but an opening has recently been cut artificially through

Fig. 11—Young depressed coast of the Port Nicholson (Wellington Harbor) area of local subsidence.

the natural breakwater. Considered as a spit the "Boulder Bank," as it is called, is of interest on account of the coarseness of the material of which it is built.

The drowning of the coast is very pronounced on the east side of Tasman Bay in the area known as the Marlborough Sounds, where rias penetrate far inland among mountains 2,000 to 4,000 feet in height (Fig. 14).

To the southeast there is then an abrupt transition to an uplifted district (eastern Marlborough) separated from the Sounds district only by the delta of the Wairau River (which is built into Cloudy Bay, a branch of the Cook Strait depression). The eastern Marlborough coast has been ascribed by the writer to the multicycle fault-coast type.[20]

Eastern Coast

Farther southward along the eastern coast of the South Island the features characteristic of very recent uplift fail and are replaced by others

[20] C. A. Cotton, paper cited in footnote 1, pp. 33-41.

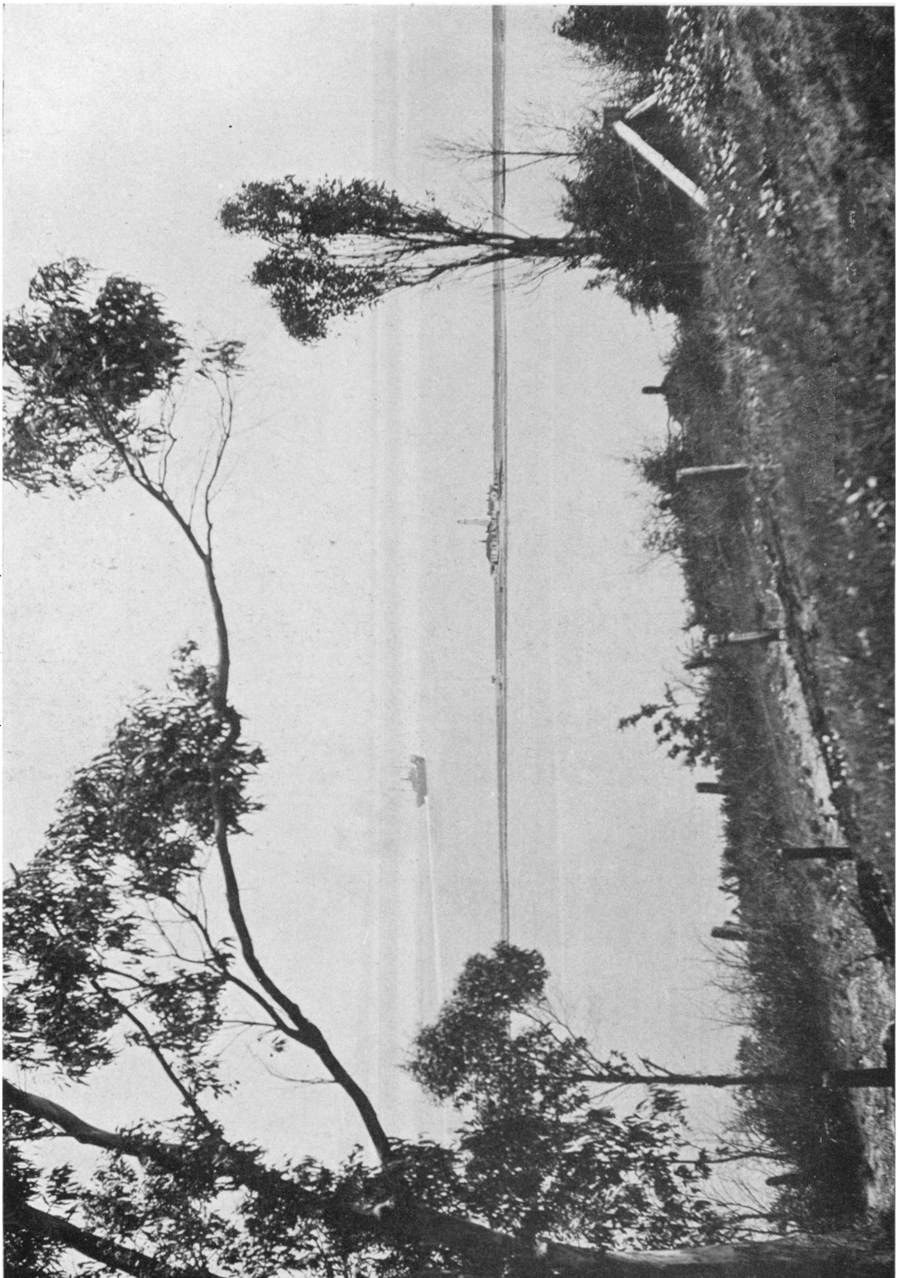

FIG. 12—The Nelson Boulder Bank.

indicating subsidence, particularly at Banks Peninsula. The same subsidence is known to have affected the adjacent parts of Canterbury, but the coastal features characteristic of subsidence are limited to Banks Peninsula, as the adjacent coasts are strongly prograded. Banks Peninsula (Figs. 15 and 16) forms a very prominent salient beyond the seaward margin of the Canterbury Plain. Originating as an island formed by a cluster of volcanoes that has been dissected and depressed, it is now tied to the shore line of the plain by the growth of bars of gravel from the south

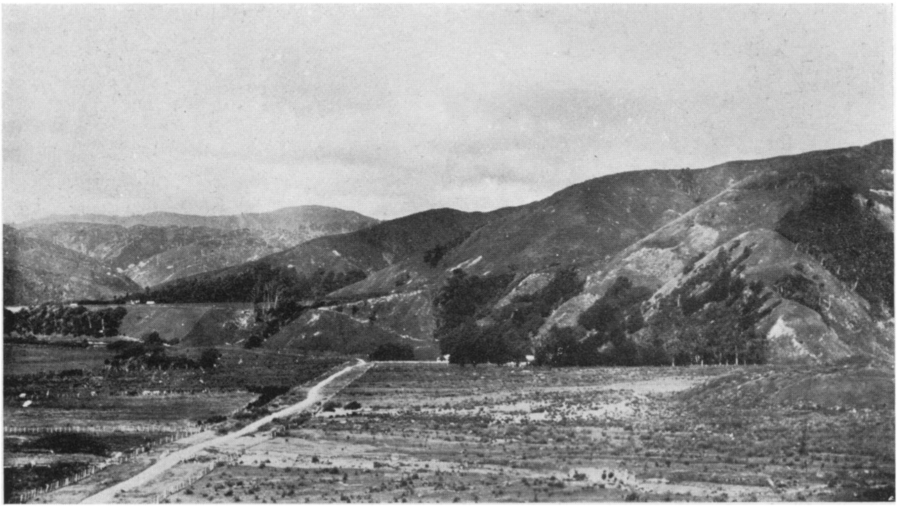

FIG. 13—Fans at Paekakariki, western Wellington, built in front of an ancient coast and afterwards cut back by the sea. In front of the newer line of cliffs lies a strand plain.

and of sand from the north, the great lagoon enclosed between which has been partly filled, with the formation of a large area of low-lying land.[21]

BANKS PENINSULA

The two largest of the drowned valleys of Banks Peninsula are the harbors of Lyttelton and Akaroa (Fig. 17). They penetrate into the hearts of the two main volcanoes of the complex and are enlarged to great basin-like hollows owing to the monoclinal retreat of the inward-facing escarpments of the lava sheets. Speight,[22] therefore, retains for them the term *calderas,* applied by Von Haast.

CANTERBURY PLAIN COAST

The Canterbury Plain is made up of confluent gravel deltas,[23] and its shore line has advanced seaward owing to accumulation being more rapid

[21] Julius von Haast: Geology of the Provinces of Canterbury and Westland, New Zealand, Christchurch, 1879, pp. 400-401.

[22] R. Speight: The Geology of Banks Peninsula, *Trans. and Proc. New Zealand Inst.*, Vol. 49, 1917, pp. 365-392.

[23] Julius von Haast, *op. cit.*, p. 396.

than subsidence. Southwards of Banks Peninsula the plain is fringed by the Ninety Mile Beach, the northern end of which forms the isthmus that ties the peninsula to the plain on the southern side. Abundant gravel brought down from the Southern Alps by the rivers that cross the Canterbury Plain travels northward along the shore line and causes progradation in an increasing degree towards the peninsula, which arrests further movement of the gravel. One after another the drowned valleys on the south side of the peninsula are being cut off from the ocean by gravel bars. Lake

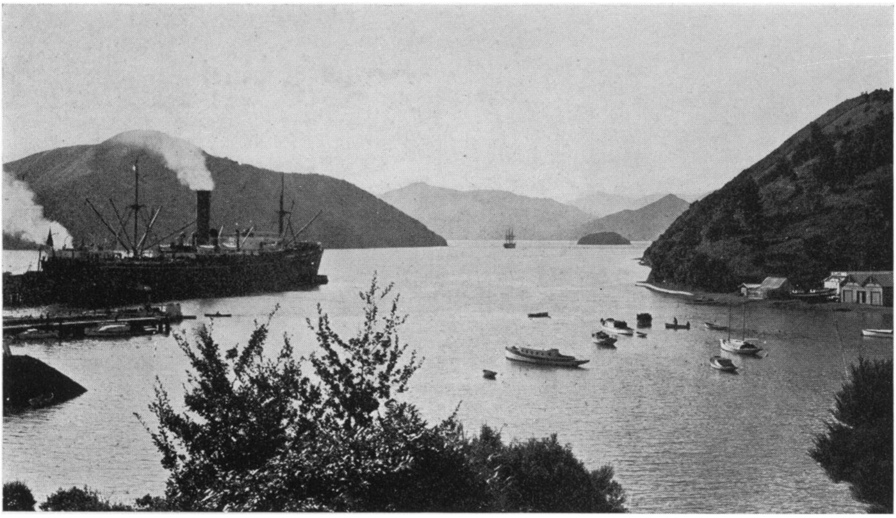

FIG. 14—In Queen Charlotte Sound, Marlborough Sounds district.

Forsyth, the largest of these and the last to be closed, is said to have been sufficiently open to be useful as a boat harbor in the early part of the nineteenth century, though now closed and converted into a brackish lake[24] (Fig. 16).

TIMARU

The northward drift of gravel along the shore line is still prominent at the southern end of the Canterbury Plain, much gravel being brought down by the Waitaki River farther south. The gravel drift is made manifest at Timaru owing to the obstruction caused by the harbor works. When the construction of an artificial harbor at Timaru was first contemplated it was proposed to have it some distance out from shore in order to allow the gravel to travel past along the beach. This scheme was not adopted, however, and a harbor was enclosed between two curved breakwaters extending out from the shore. In a few years the obstruction thus formed had caused a broad prograded strip to grow on the southern side, the har-

[24] R. Speight, *op. cit.*, p. 370.

bor was rapidly being filled up, and it was found necessary to run a new wall straight out seaward as a "shingle trap." In the future, further extension of this wall will probably be required. One curious result of the

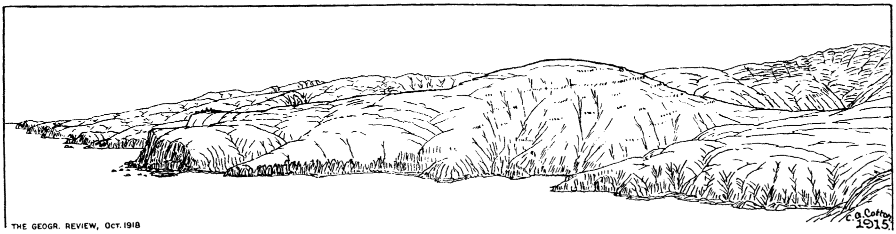

FIG. 15—The northern side of Banks Peninsula. The entrance to the harbor of Lyttelton lies beyond the first headland.

stoppage of the movement of gravel along the shore is that the beach immediately under the lee of the harbor works, known as Caroline Bay,

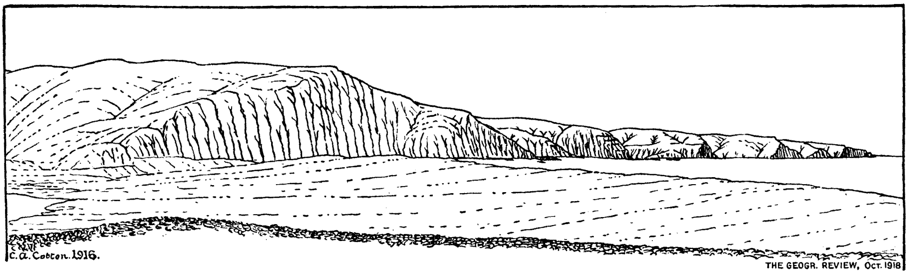

FIG. 16—The southern side of Banks Peninsula, from a gravel ridge on the Ninety Mile Beach. The recently closed bay, Lake Forsyth, is on the left.

which was formerly part of the gravel beach, is now covered with sand, being the only sandy beach for many miles. The possession of this beach has converted Timaru into a summer resort.

OAMARU AND OTAGO

Southward of Timaru the delta of the Waitaki repeats the features of the Canterbury Plain coast, while beyond it, at Oamaru, a mature cliffed coast begins, cut on weak rocks with moderate relief and fringed by a narrow strip of coastal plain, now cut back to cliffs some forty feet in height. The accumulation of the young littoral sediments of this strip marks a period of downward oscillation preceding the small uplift which was the last movement and which laid bare the narrow coastal plain and initiated the retrogradation that has reduced it to a discontinuous terrace.[25]

[25] This is the "42 ft. raised beach" of Park (J. Park: The Geology of the Oamaru District, North Otago, *New Zealand Geol. Survey Bull. No. 20* (*N. S.*), Wellington, 1918, pp. 19 and 112). The so-called "12 ft. raised beach" is the platform and bed of gravel at the base of the young coastal plain sediments.

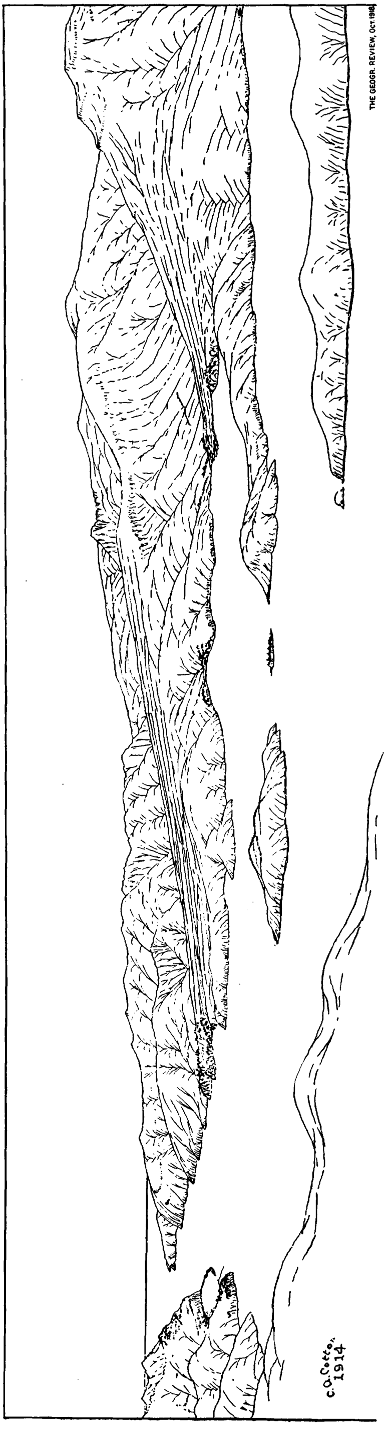

Fig. 17—Port Lyttelton, Banks Peninsula.

Farther south a young drowned coast is again prominent, the maximum of embayment being found on the volcanic massif of Otago Peninsula. Here is a great quantity of sand traveling northward along the shore, which has more or less completely closed the inlets (Fig. 18), Otago harbor being the only one that is navigable. Otago harbor results from the drowning of two valleys and the divide between them, but one entrance to the strait thus formed is now closed by a sand isthmus connecting Otago Peninsula with the mainland.[26] Upon the isthmus part of the city of Dunedin is built.

Foveaux Strait and Stewart Island

The coast line for some distance southwestward from Otago Peninsula is practically mature, but as Foveaux Strait is approached embayments again appear, probably partly as a result of the slower rate of erosion in more sheltered waters. Stewart Island, as well as the opposite mainland shore, is deeply embayed, and Foveaux Strait, which lies between, may be due entirely to general subsidence, though it is quite possible that a strait had been formed by local subsidence, as Hochstetter supposed,[27] prior to the general subsidence. The deep indentations of the eastern side of Stewart Island form fine harbors, but the exposed, western coast has been much straightened by the cutting back of headlands and the filling of bays with sand.

Western Coast

The western coast of the South Island has been shown to be at least in its

[26] Patrick Marshall: The Geology of Dunedin (New Zealand), *Quart. Journ. Geol. Soc.*, Vol. 62, 1906, pp. 381-424; reference on p. 384.

[27] F. von Hochstetter, work cited in footnote 5.

northern part one of those rather recently uplifted and subsequently cut back by erosion.[28]

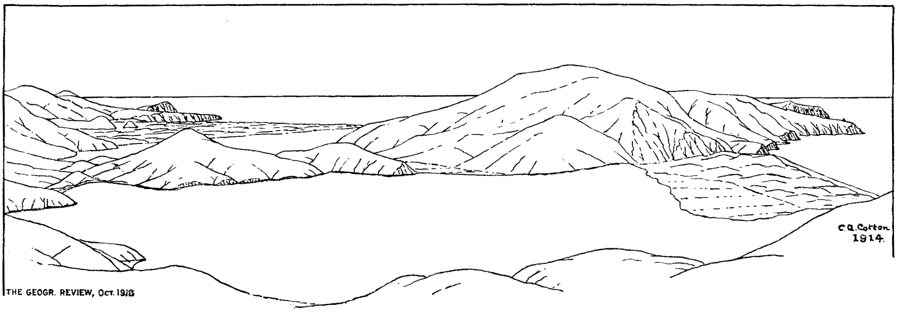

FIG. 18—Embayments closed by sand bars, Otago Peninsula.

This coast bounds a group of high faulted blocks, and its original outline was probably determined by a fault line. The present maturity of

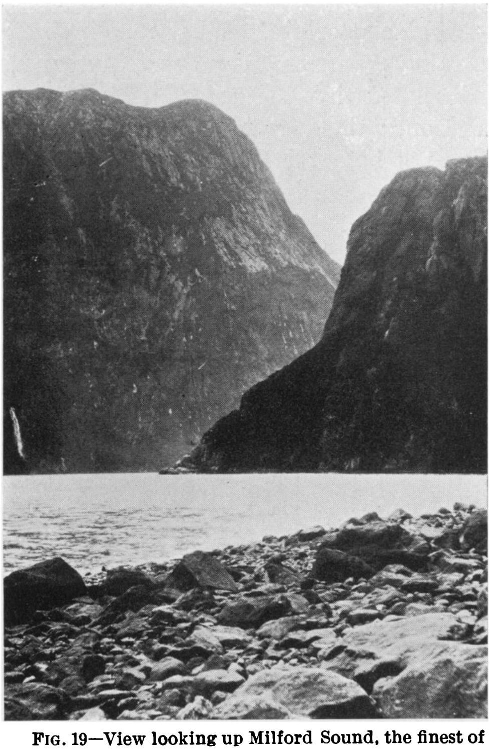

FIG. 19—View looking up Milford Sound, the finest of the New Zealand fiords. Stirling Fall (500 ft.) spouts from the mouth of a hanging valley on the extreme left, and the sheer precipice beside it is 3,000 feet high.

outline and high, bold cliffs of the west coast are to be largely ascribed to

[28] J. A. Bartrum: The Geological History of the Westport-Charleston High-level Terraces, *Trans. and Proc. New Zealand Inst.*, Vol. 46, 1913, pp. 255-262.

the enormous energy of the waves driven before the westerly winds of the "roaring forties." The supply of waste from the mountains is so great, however, that parts of the coast are prograded in spite of the great energy of wave action. Recent inroads made by the sea on the town of Hokitika, which is built on a strand plain, point to alternation between periods of progradation and retrogradation similar to those noted on other sections of the New Zealand coasts.

The Fiord District

In the southwestern, or fiord, district the deep offshore soundings and the sweeping curve of the shore line seem to indicate without doubt a fault origin for the outer coast. This is suggested in a map by Park.[29] The occurrence of high benches which appear to be cut platforms suggests a multicycle origin. Much has been written about the fiords or "sounds" of this section of the coast,[30] which resemble the fiords of Norway, and it is not proposed to discuss them at length here. The existing features of the fiords are clearly of glacial origin. What remains in doubt is the origin of the preglacial valleys, whether these were insequent, fault-guided, or tectonic. It may be noted that the generalization emphasized by Gregory in a recent publication,[31] that the most typical fiords are straits parallel with the coast, does not hold for New Zealand, where there are no longitudinal fiord straits, unless the inland "fiord" Lake Te Anau be regarded as taking the place of these.

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[29] J. Park, work cited in footnote 12, p. 265.

[30] See especially J. W. Gregory: The Nature and Origin of Fiords, London, 1913, pp. 350-368.

[31] J. W. Gregory: Fiords and Earth Movements, *Scientia*, Vol. 20, 1916, pp. 253-264.